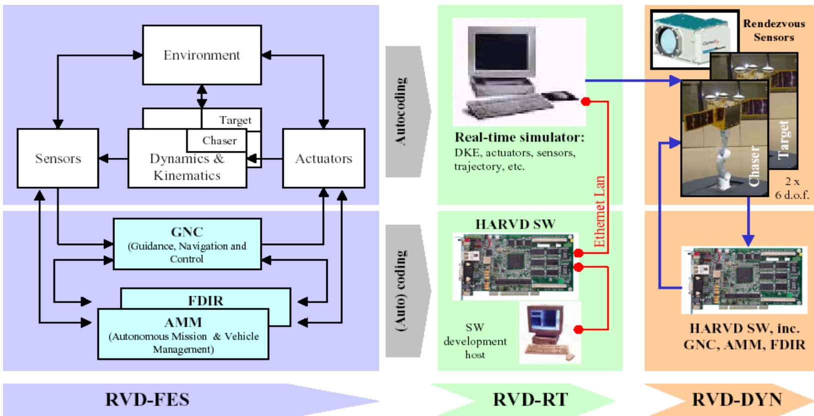
AGASSE-2010

MULTI-SENSORS BASED CONTROL SYSTEM FOR GENERIC AUTONOMOUS RVD

ACTIVITY PERIMETER

- What is HARVD?

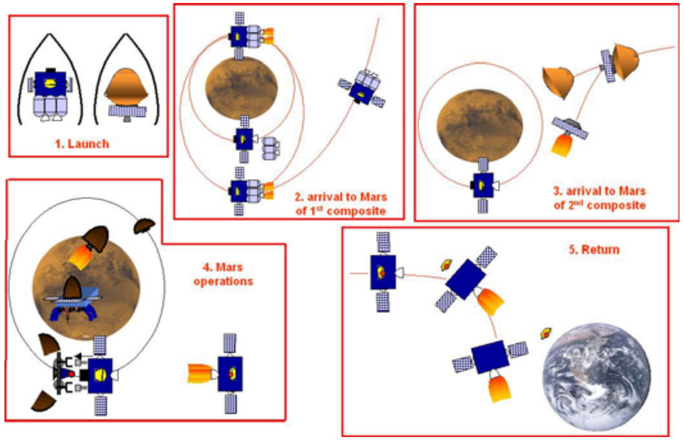
1. Autonomous control system for:
   - Mars and Earth, both in Circular and Elliptic orbits
   - Capture and docking (along different approach directions)
2. Test facility framework for:
   - **FES SW simulator**, integrating HARVD algorithms (Matlab/Simulink)
   - **Real-Time test bench** with Processor in the Loop, integrating HARVD SW demonstrator (automatic code generation with TargetLink tool)
   - **Dynamic test bench** (based on GMV's PLATFORM) with Processor and Sensors (air-to-air stimulation) in the Loop
3. DVV approach definition
   - Validation at algorithm level supported by FES SW simulator ➔ **TRL 3**
   - HARVD SW Demonstrator building based on autocoding techniques ➔ **TRL 4**
   - Validation at SW level supported by RT and DYN test benches ➔ **TRL 4 / 5**



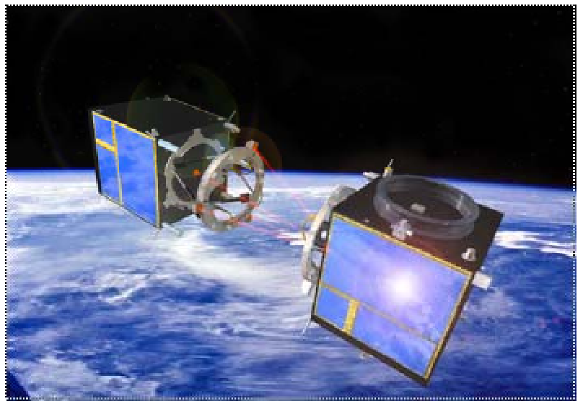
REFERENCE MISSIONS FOR HARVD SYSTEM

2 reference missions in different scenarios and covering all rendezvous control system needs

- **MSR: RendezVous around Mars for sample return**
  - based on ESA MSR mission (Phase A2)
  - Capture (canister) and Docking (MAV) scenarios
  - Circular (500km, 30°) or Elliptical (300 x 2200km or 218 x 500km) rendezvous orbits
  - Cooperative and Uncooperative target (for relative measurement)

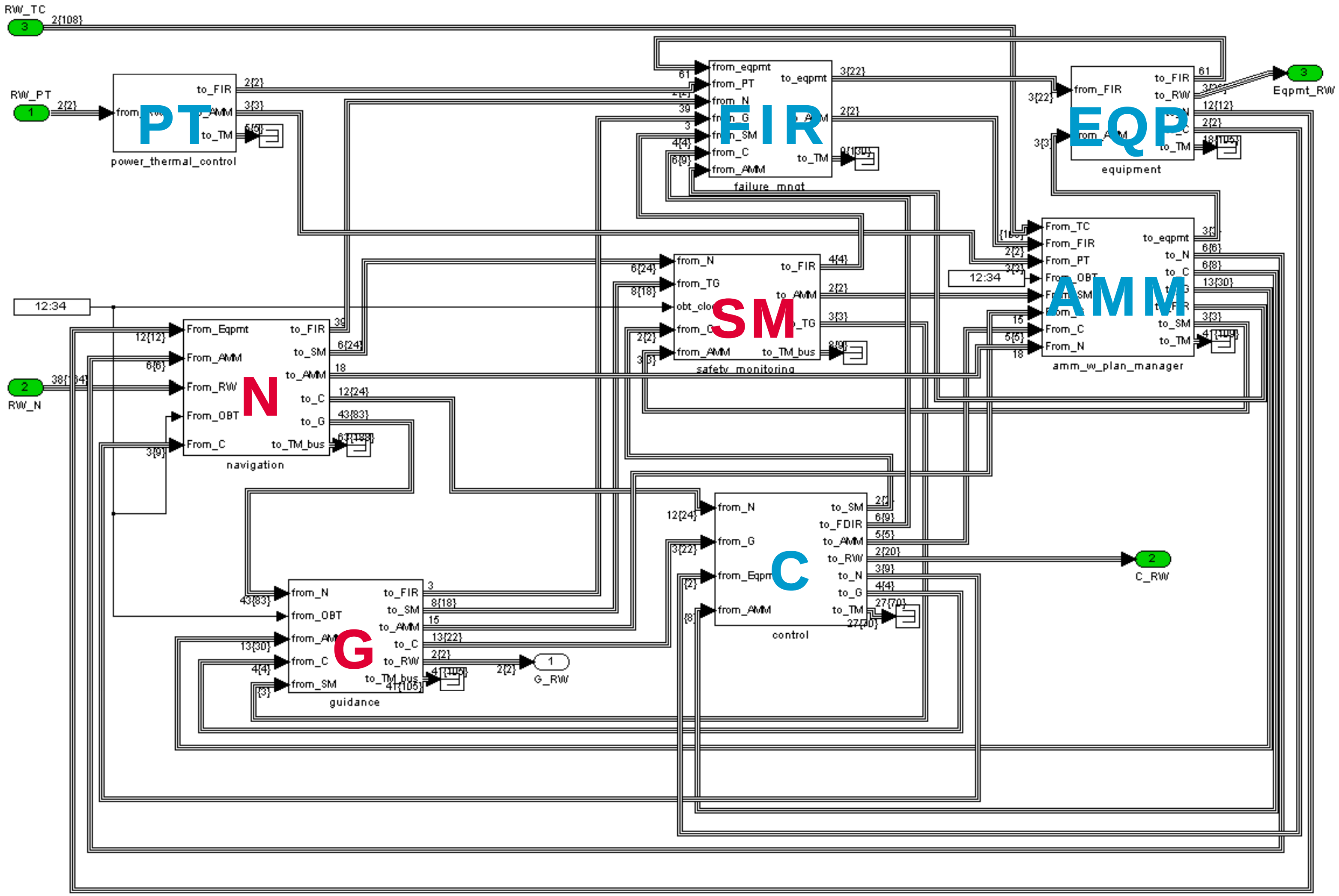


- **RVDM: Rendezvous Demonstration Mission**
  - based on ESA definition study for IBDM validation
  - Circular (560km) or Elliptical (500 x 620km) rendezvous orbits
  - Docking scenarios
  - Different approach directions



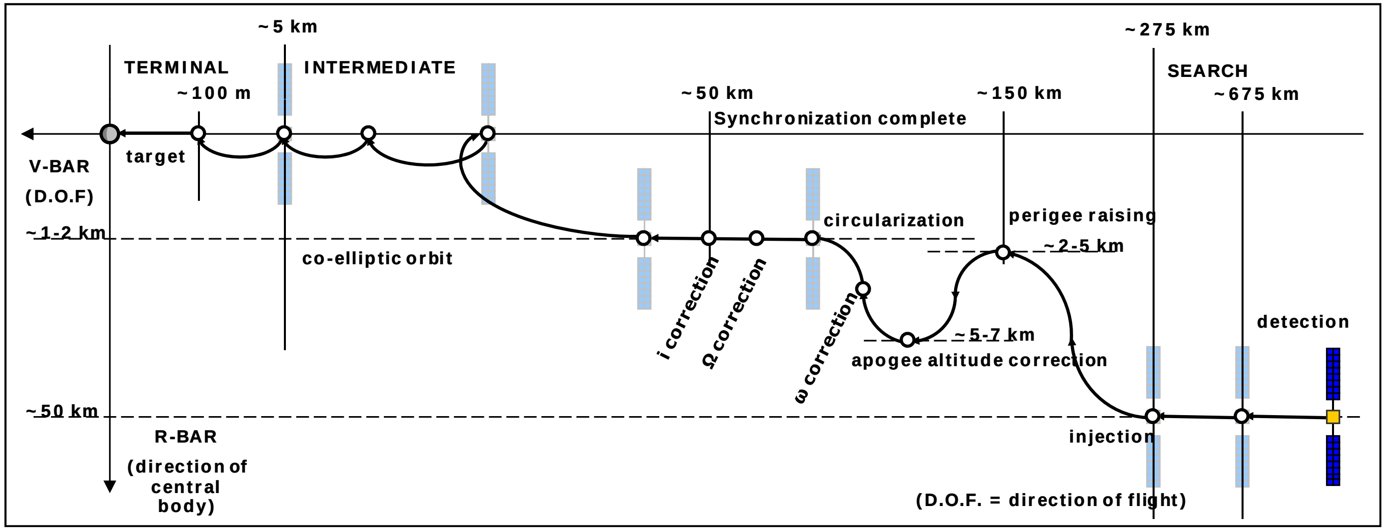
HARVD DESIGN: HIGH LEVEL ARCHITECTURE

- Every function (e.g Navigation) design shall take into account (coupled design/ constraints) that is integrated within the full HARVD GNC System



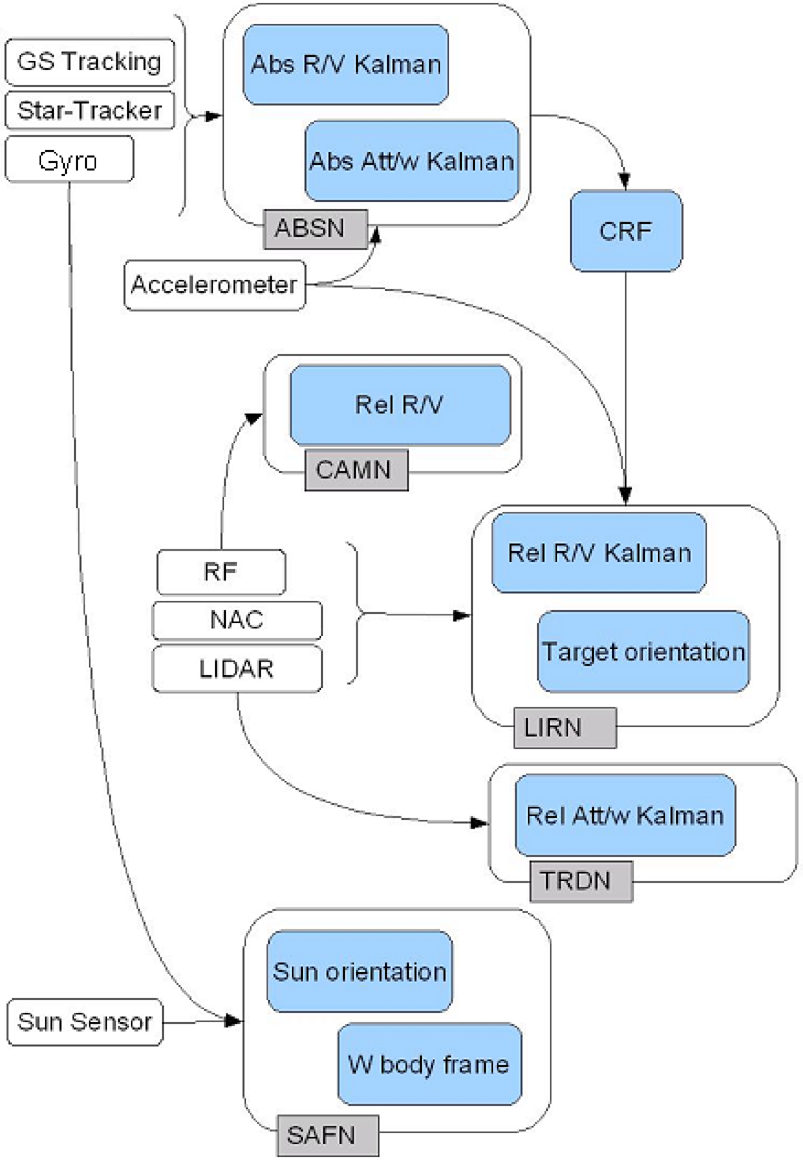
HARVD DESIGN: MISSION PHASES

- The MSR mission is conceptually separated in three main phases, which facilitate the logical subdivision at mission plan and GNC mode level:
  - Long Range Phase: Orbiter and SC are at long distances (100s/1000s of km). Once the relative free drift motion between the satellites has taken both to a distance lower than the relative sensors range (100s of km), the Orbiter starts the SC acquisition, goal of this phase.
  - Intermediate Range Phase: the SC acquisition has been successfully completed and the Orbiter shall manoeuvre to synchronize its orbit with respect to the SC one (achieving a final position of few km behind the SC in its ±V-bar direction).
  - Short Range Phase: after the SC V-bar has been successfully reached, the Orbiter starts the approach toward SC, completed with the final capture.



HARVD DESIGN: NAVIGATION

- The Navigation function design is in agreement with the mission phases
  - Absolute sensor suite: classical and consolidated approach
  - Relative sensor suite: tricky trade-off is needed, mainly at long range. Criteria for the trade-off are, among others:
    - Range limit
    - Performances
    - Robustness to failures and to scenario conditions (e.g. illumination conditions)
    - Adaptability to contingency scenarios
    - Acquisition times
    - Mass/Power requirements
    - Reliability



HARVD DESIGN: SENSOR SUITE @ LONG RANGE

- Long-range phase main challenges
  - Detection
  - Navigation

- Target detection at long range: trade-off for relative sensors and range
  - Target detection within the first detection window, otherwise a ΔV penalization (RAAN differential drift) ~ 115 m/s and RdV delay of several days (power constraints) shall be taken into account ➔ **wide or omni-directional coverage is recommended**
  - 400 km sensors range to allow HARVD navigation filter convergence and approaching manoeuvre execution w/o loosing target observation during the manoeuvre
  - NAC Optical camera for angular LOS measurements: canister optic magnitude at 400 km is lower than complete stars database ➔ additional wide FOV active sensor is needed to speed up canister detection through scanning in a limited sky portion
  - Extended RF sensor (wrt PRISMA/PROBA3) as precise ranging sensor (1 m at long range) with coarse LOS (30 deg) ➔ **new sensor development**

SENSORS BASELINE

- Absolute Navigation sensors trade-off and selection

Sensor	Physical Measurement	Applicability to MSR	Applicability to RVDM
Ground Tracking	Absolute position and velocity wrt Mars centered j2000 frame	Yes	Yes. Replaceable by absolute GNSS in most cases because of cost
Absolute GNSS	Absolute position and velocity wrt Earth centered j2000 frame	No	Yes
Coarse Sun Sensor	Sun direction in spacecraft frame	Yes	Yes
Star-Tracker	Absolute attitude quaternion (wrt j2000 inertial frame)	Yes	Yes
IMU	Absolute angular rate (wrt j2000 inertial frame) Absolute linear acceleration (wrt j2000 inertial frame)	Yes	Yes

- Relative Navigation sensors trade-off and selection

<table>
<tr><th colspan="2" rowspan="2">Sensor</th><th colspan="5">Range region</th></tr>
<tr><th>1 m – 1 km</th><th>1 km – 5 km</th><th>5 km – 30 km</th><th>30 km – 410 km</th><th>410 km – ...</th></tr>
<tr><td colspan="2">NAC</td><td colspan="2">Pictures</td><td>Medium/Fine LOS</td><td>Fine LOS</td><td>Contingency search</td></tr>
<tr><td rowspan="2">RFS2</td><td>L Mode</td><td>X</td><td>X</td><td>X</td><td>Fine ranging & coarse LOS</td><td>X</td></tr>
<tr><td>S Mode</td><td>CAM sensor</td><td colspan="2">Fine ranging & medium LOS</td><td>X</td><td>X</td></tr>
<tr><td colspan="2">LIDAR</td><td colspan="2">Fine ranging & Fine LOS</td><td>X</td><td>X</td><td>X</td></tr>
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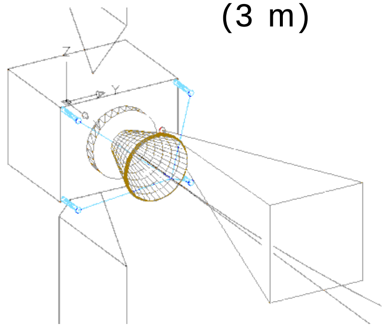
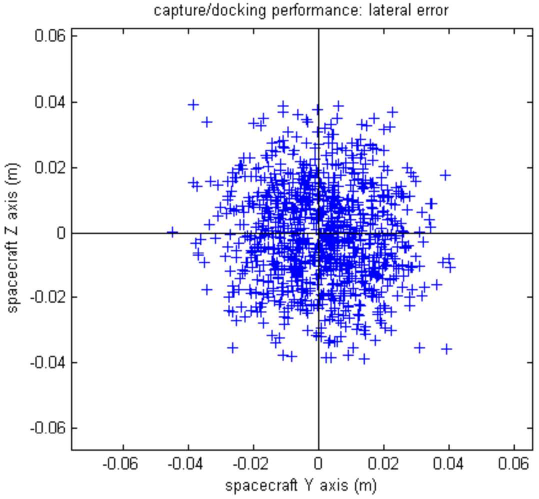
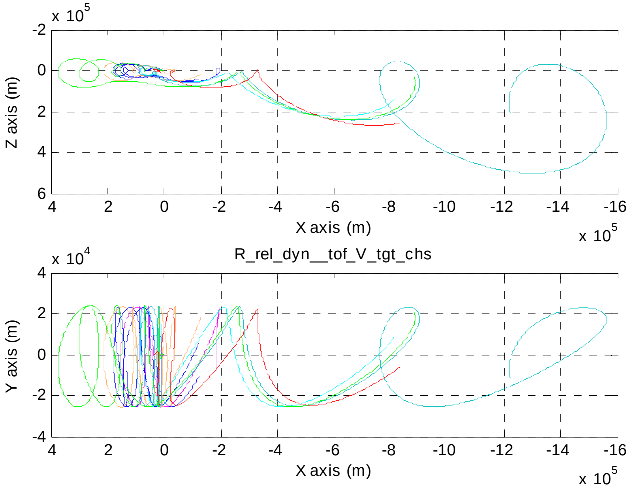
Blind phase
(3 m)

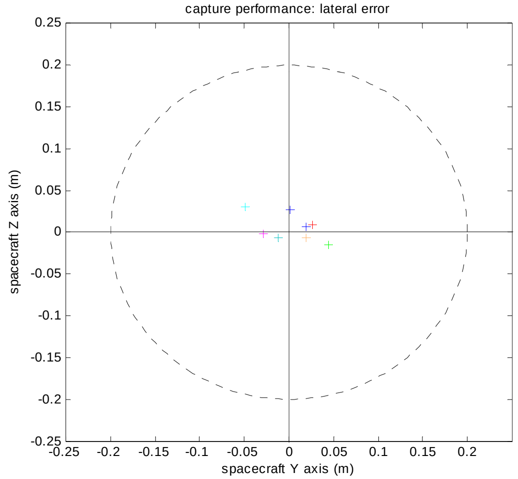


MSR Main results

- 1000 shots Montecarlo of forced motion phase, scattering:
  - Mass
  - Inertia tensor
  - Flexible modes
  - CoG position
  - Initial target true anomaly
  - Initial chaser relative state vector
  - Sensors biases and noises
  - Actuators misalignments and noises
- Deterministic scattering for long range scenarios:
  - Target true anomaly
  - Initial Delta elements
  - CoG position (worst cases)
  - Inertia tensor, flexible modes (worst cases)
  - Sensors errors (worst cases)

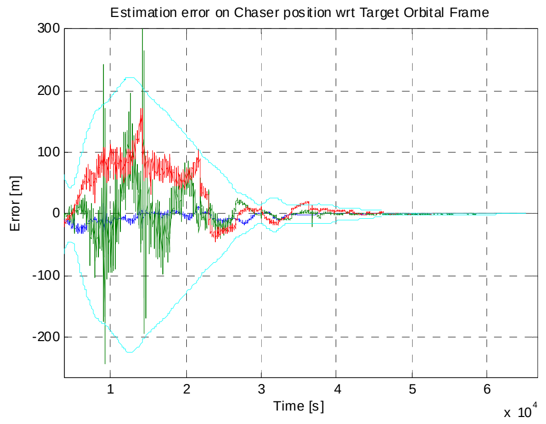


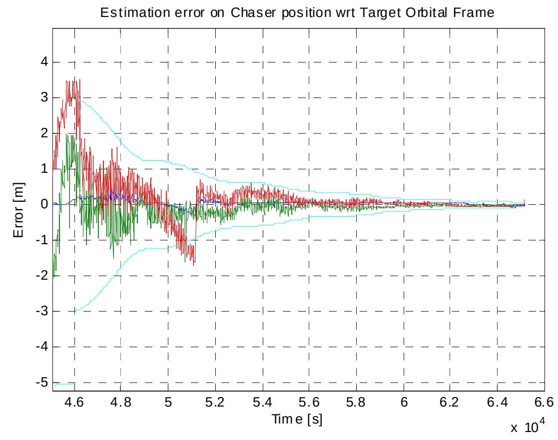


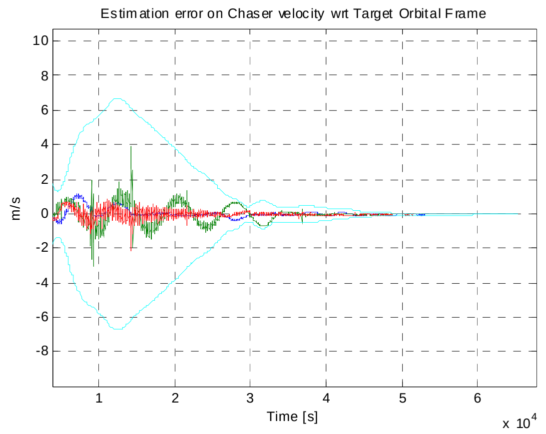


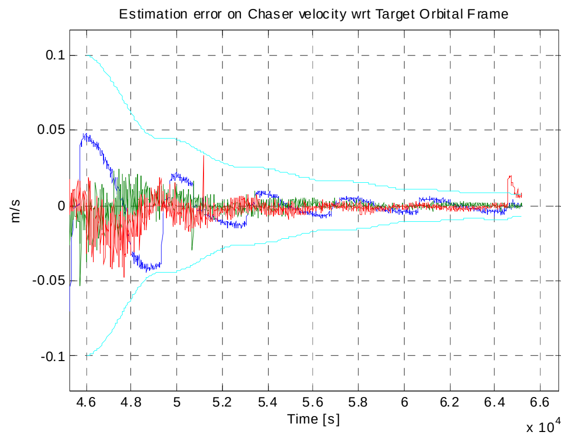
Navigation Performances

- Navigation requirement (in cyan) fulfilled for both position and velocity, at long and short range
- Some sporadic exception, not influencing the overall GNC & mission requirements



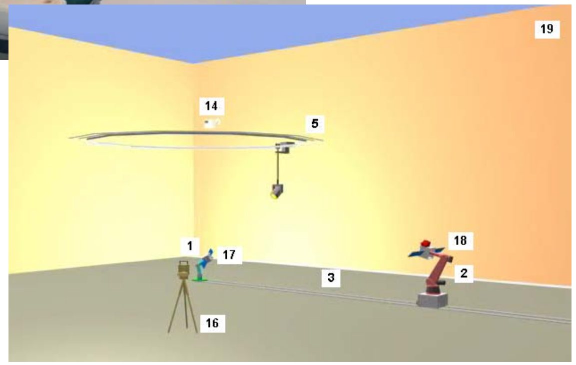






TEST BENCHES

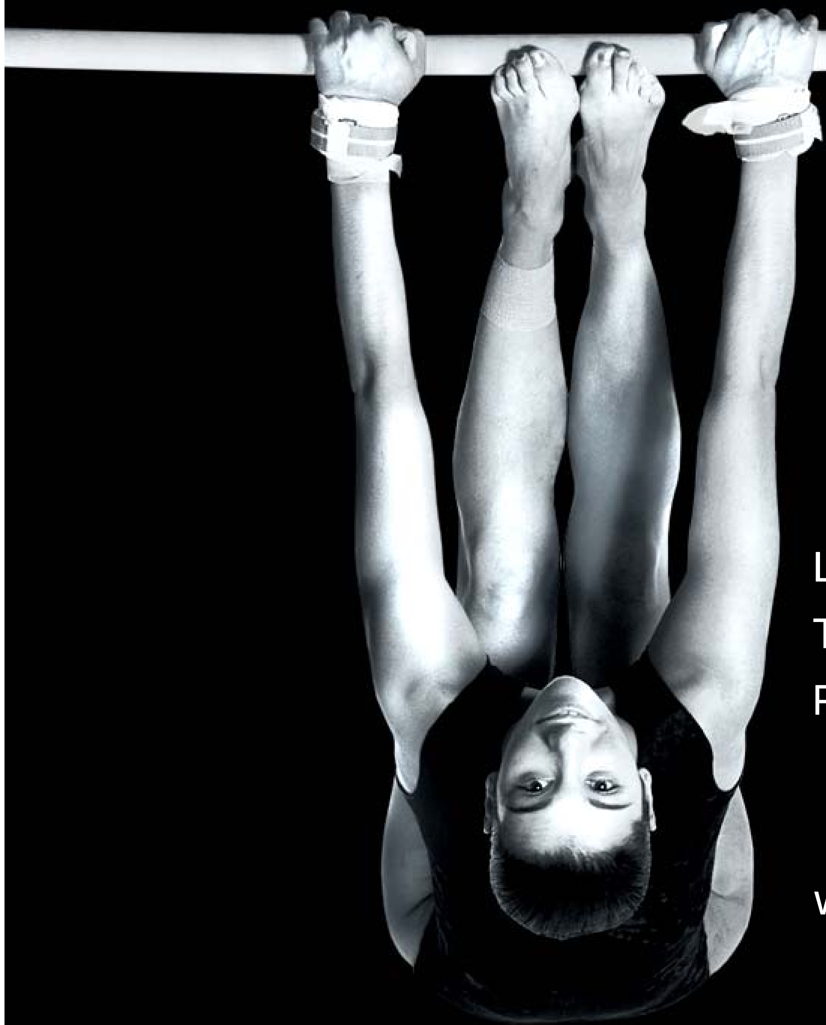
- Sensors suite selection and navigation design TRL is being increased to TRL 4/5 through:
  - Real-time Processor-in–the-Loop test bench
  - Real sensors air-to-air and dynamically stimulated in HW-in-the-loop test bench
- Autocoding activities already finished
  - On-board software generated with TargetLink
  - Test campaign repeated with Software In the Loop simulator
  - Same behaviour obtained wrt. FES ➔ Autocoding process validated
- RT Avionics and Dynamic Test Benches activities on-going
  - RvD-RT PIL test bench with FPGA board (with a Leon-2 bitfile model)
  - RvD-DYN HIL adds real sensors equipment and dynamic devices for air-to-air sensors stimulation.



Nb.	Description
1	Target 6DOF Robotic Arm + controller
2	Chaser 6DOF Robotic Arm + controller
3	Servo controlled track motion (15 m, including control module)
5	Illumination system (lens, lamp mount and servo controlled circular track)
8	Net devices (router, switches, wireless modem, wires)
9	Monitoring and Control processor units (PCs)
13	GPS navigation receiver + antennas (Septentrio PolaRx2)
14	GPS-like pseudolites + wireless control modems and control unit (NavIndoor System)
16	Laser calibration absolute station (Pentax R-315N)
17	Target S/C for reference Rendez-vous scenarios mock-ups
18	Chaser S/C for reference Rendez-vous scenarios mock-ups
19	Building and facilities

POSSIBLE FUTURE IMPROVEMENTS IN SENSORS SUITE AREA

- Possible improvements on mass/propellant/power budget
  - Sensors miniaturization
  - Operational range is a key factor for an efficient rendezvous approach
    - Earlier target detection -> less approach manoeuvres, less DV, shorter mission duration
    - Following the investigations on Prisma RF extension very desirable for rendezvous missions
  - Higher accuracy of RF LoS at long range => reduction of the target acquisition time
  - Further reduction on bias and noise levels would improve the navigation solution especially at long range => more precise manoeuvres => less DV
  - Relative velocity measurements should be refined, decreasing the level of noise/bias and providing 3D observations (i.e. not only range rate, but also LoS rate)
- Possible simplification of ground operations => reduction of mission costs
  - Consider on board sensors providing absolute position and velocity measurements (e.g. optical navigation based on Moons) => increase autonomy level => reducing ground operations



Thank you

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